EARLY DEVONIAN IGNEOUS ACTIVITY AND SOME STRATIGRAPHIC CORRELATIONS IN THE TUMUT REGION, NEW SOUTH WALES

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Synopsis

North of Talbingo, the Tumut River in southern New South Wales traverses a belt of folded Silurian metasediments and volcanic rocks, the latter being part of an extensive association here named the Wiradjuri Volcanics. Several bodies of sub-volcanic leucogranite (the Gocup and Bogong Granites, and the Killimicat and Lobs Hole Adamellites) postdate the rocks of this belt and exhibit clear petrographic and chemical affinities. Ignimbritic rhyolites of the Buddong and Minjary Volcanics and the Gatelee Ignimbrite are stratigraphically equivalent, spatially associated with these leucogranites, and also comprise a petrologically coherent group. New radiometric and palaeontological evidence indicates that both groups are of Early Devonian age and enables regional stratigraphy to be refined. The ignimbritic rhyolites may represent the extrusive equivalents of the leucogranites but other volcanic and plutonic rocks of post-Silurian age in the area are clearly unrelated to this magmatic episode.

INTRODUCTION

The town of Tumut, 70 km due west of Canberra, is situated within a belt of folded rocks that comprises the southern part of what has been recently termed the Bogan Gate Synclinorial Zone (Scheibner, 1974). These rocks were deposited in the southwestern portion of the Cowra Trough (Packham, 1969, p. 6). A broad two-fold division is characteristic of much of this belt : a unit dominated by porphyritic rhyodacites and pyroclastic rocks of rhyolitic to dacitic composition, with intercalated sedimentary material of varying prominence, overlies more strongly deformed rocks of diverse lithology which include shales, siltstones, phyllites, basic schists, serpentinites and minor marbles. Several granitic bodies intrude the rocks of this belt, and it is unconformably overlain in places by more gently folded supracrustal rocks of Early to Late Devonian age.

In the Tumut region, this belt appears between the Burrinjuck-Young Batholith in the east, and the Wagga Metamorphic Belt and Wondalga Granite to the west. The upper unit in this area has been named the Blowering Beds (Ashley *et al.*, 1971, after Adamson, 1960*a*). Less is known of the more complex lower unit—it includes at least the Bullawyarra Schist and Bumbolee Creek Beds, and possibly the Honeysuckle Beds and Coolac Serpentinite. All these have been discussed by Ashley *et al.* (1971), who have also described the Bogong Granite and Killimicat Adamellite, which intrude the folded succession east of Tumut, and the Gatelee Ignimbrite, which overlies it unconformably.

Northwest of Tumut, however, previous geological investigations have been limited to broad reconnaissance studies such as that of Adamson (1960*a*). A granitic stock in this region is here named the Gocup Granite, the name being taken from the village of Gocup situated 1 km from its eastern boundary.

This paper describes the Gocup Granite and associated rocks, as well as occurrences of similar lithologies over a much wider area (see Fig. 1). New palaeontological, radiometric and petrological investigations have enabled part of the sequence of sedimentation, granitic intrusion and volcanic activity in the area to be dated accurately and allow a refinement of regional stratigraphy.

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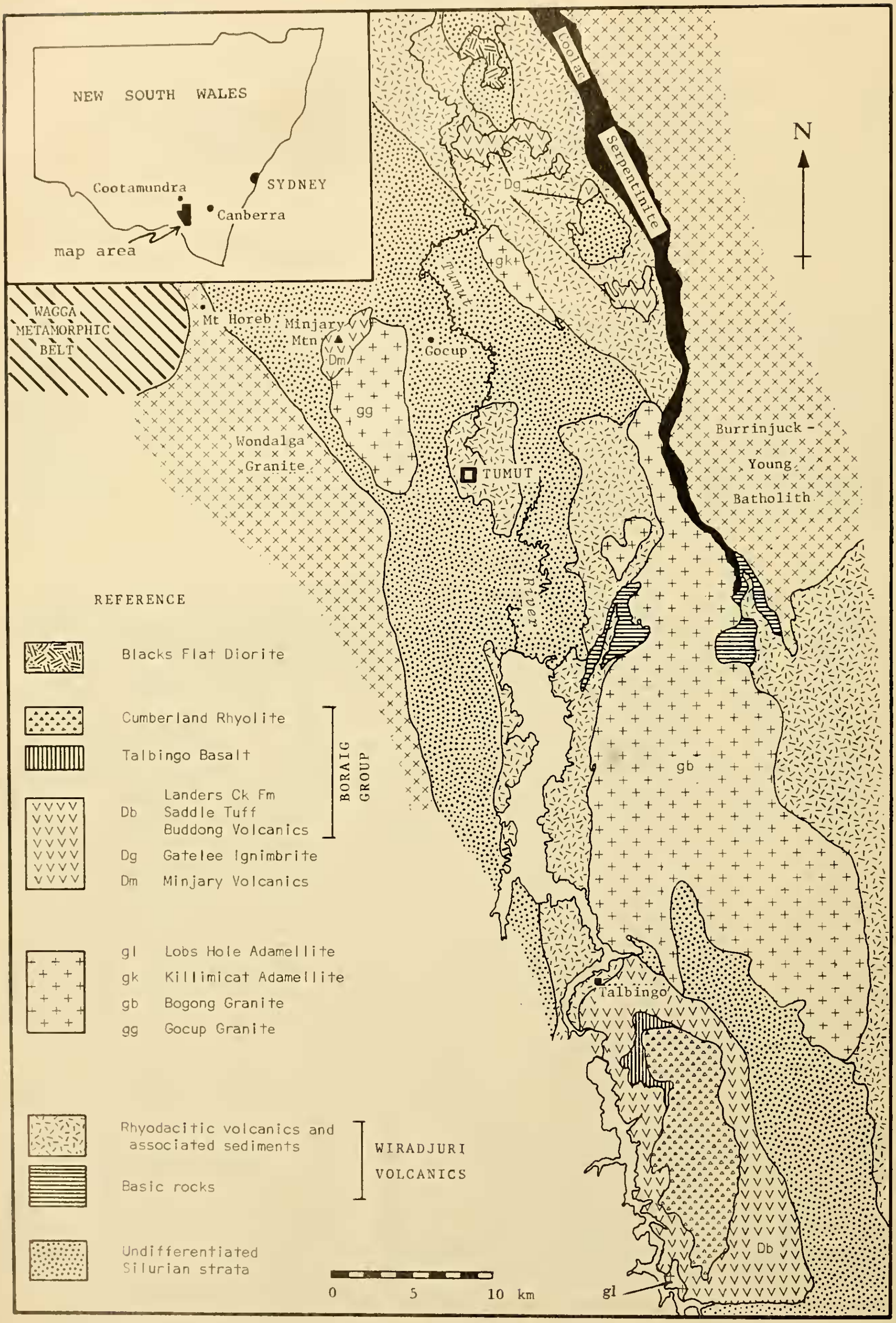

Fig. 1. Geological sketch map of the Tumut District. (Modified from Adamson and Loudon, 1966, and Ashley *et al.*, 1971). For stratigraphic relationships see Fig. 2.

Geology Northwest of Tumut

Metasediments

An extensive succession of folded low-grade metamorphic rocks of unknown thickness is intruded by the Gocup Granite. In and north of Tumut, this succession is overlain by porphyritic rhyodacites and tuffs of the Blowering Beds. The metasediments consist mainly of phyllite, lithic sandstone and thinly-bedded quartz-siltstone, with subordinate conglomerate, marble, volcanic breccia and tuff. These rocks have undergone regional metamorphism only to lower greenschist facies ; chlorite is extensively developed. A closely-spaced subvertical cleavage striking from 5° to 20° west of true north is widespread, and sedimentary structures are rarely observed. Deformation is most intense in the narrow septum of metasediments separating the Wondalga and Gocup Granites, where bedding is generally obliterated by two sets of overprinted cleavage, the second parallel to the axial planes of tight, locally isoclinal, mesoscopic folds in the earlier-generation cleavage. The fine-grained phyllites from this belt contain 40–60% rounded quartz grains (average diameter 0·02 mm) in a sheared matrix of finer-grained quartz, muscovite, chlorite and limonite. Relict, fractured plagioclase grains of composition around An_{30} characterise the tuffaceous material, which may have been andesitic, but is now extensively chloritised. In addition, local occurrences of actinolite schists, which become more prominent northwest of the Gocup Granite, attest to the presence of more basic rocks in the original sequence.

East of the Gocup Granite, the sediments are less deformed, though the penetrative cleavage is still characteristic. Quartz-rich siltstone with limonitic cement is the dominant rock type, with some coarser-grained lithic sandstone and greywacke. These rocks are very similar to the Bumbolee Creek Beds of Ashley *et al.* (1971), a sequence of slaty shales, siliceous siltstones and lithic sandstones exposed extensively east of the Tumut River. Both units are overlain by the Blowering Beds and stratigraphic equivalence is suggested.

Marble and Serpebtinite

Small pods of marble occur *en echelon*, trending about 20° west of north, within the belt of metasediments separating the Group and Wondalga Granites. This marble is foliated, and consists almost entirely of white, fine-grained, recrystallised calcite, with occasional cherty nodules and talc bands. Parasitic and kink folds mirror the deformation in the surrounding phyllites and siltstones. Isolated exposures of similar marble occur along strike both to the north and south. The horizon extends north-northwest to at least a point east of Mount Horeb where the rock was quarried last century (Carne and Jones, 1919, p. 350), while to the south it is exposed discontinuously over a distance of some 15 km parallel to, and east of Gilmore Creek.

Serpentinite is found in this narrow belt of country rocks at isolated localities along much the same zone as the marble described above, though the two rock types have not been observed in contact. The serpentinite is composed of reticulate masses of fine-grained serpentine minerals, with larger grains of altered pyroxene (bastite) and pale sea-green antigorite. Anthophyllite, picotite, magnetite and chlorite are present in smaller amounts. A relic igneous texture is apparent, and these rocks are considered to have had an original composition of peridotite or harzburgite. Quartz-magnetite-hematite rocks are associated with the serpentinites.

Age

In spite of the pronounced deformation and recrystallisation in the marble pods west of the Gocup Granite, recognisable conodont fragments were found to have survived the metamorphism. These represent the only fossils recorded from strata below the Blowering Beds in the Tumut district. The fragments are of a form with an asymmetric platform ledge and a small basal cavity. They show affinities (T. B. H. Jenkins, pers. comm.) to the genus *Polygnathoides* Branson and Mehl, a platform-type conodont of Ludlovian age (Walliser, 1964). Link and Druce (1972) have recorded *Polygnathoides siluricus* and *P. emarginatus* from the middle Ludlovian Silverdale Formation of the Yass Basin.

The fauna recorded from the Blowering Beds northeast of Tumut (Ashley *et al.*, 1971) includes corals, brachiopods and graptolites generally indicative of a Silurian age, as well as the conodonts *Trichonodella inconstans* Walliser and *Ozarkodina* cf. *jaegeri* Walliser. Although this fauna may be reworked in part, it confirms a Middle to Late Silurian age, suggested on limited evidence by Adamson (1960*a*), for the whole country rock succession northwest of Tumut, thus placing an older limit on the time of intrusion of the Gocup Granite.

Gocup Granite

This body is discontinuously exposed over an elliptical area of some 42 km^2 consisting mainly of a range of hills, in part flat-topped, that rises steeply from the east and west, but more gently from the south, to an elevation of about 400 m above the surrounding country. In the northwest, on and near Minjary Mountain, the granite is overlain by rhyolitic lavas and ignimbrites of the Minjary Volcanics. Outcrop is generally good on the steep flanks of the hills but is often poor on the upper, flat to undulating central plateau which supports natural forest vegetation.

Except near its margins, the granite is massive and unstressed : joint orientations show no regular pattern and neither mineralogical nor tectonic foliation is present. The body is largely homogeneous and composed of leucogranite with an average grainsize ranging from 2 to 7 mm. The grainsize tends to decrease at topographically higher levels, possibly indicating that the Gocup Granite has not been eroded far below its original roof.

Microscopic examination reveals that quartz and alkali feldspar (perthitic microcline and primary albite) together generally comprise at least 80% by volume of the rock, the remainder being chiefly biotite, muscovite, oligoclase (as relict phenocrysts) and tourmaline, in varying proportions. Muscovite-free varieties are rare. Zircon, apatite, sphene and fluorite are present as accessories, but always collectively total less than 0·5% of the mode. Secondary alteration of the feldspars and biotite is widespread, with the appearance of sericite, epidote, clays, chlorite and hematite. Micrographic and myrmekitic quartz-feldspar intergrowths are common, especially in the finer-grained variants.

Minor rock types within the stock probably occupy less than 5% of the total outcrop area and comprise, in the main, fine-grained aplite patches and coarse quartz-rich tourmaline-bearing pegmatite veins. The former have much the same mineralogy as the host granite and are distinguished only by a mean grainsize as fine as 0·5 mm. Quartz, pink feldspar and tourmaline are the main minerals in the pegmatites, the tourmaline occurring in radiating clusters and bladed aggregates up to 20 cm in length.

Contact effects about the Gocup Granite are limited to a narrow zone, in places less than 10 m wide, in which the country rocks are indurated and brecciated. Development of a prominent metamorphic aureole, like those adjacent to the Killimicat Adamellite and parts of the Bogong Granite, is not apparent. This may be due in part to the siliceous nature of the metasediments which would preclude the development of mineral assemblages indicative of thermal metamorphism, but structural features at the margin of the Gocup Granite indicate forceful emplacement of a massive, semi-solid body to its present crustal position by upward and lateral wedging apart of country rocks that were already strongly cleaved. In the southwest, the contact with the metasediments dips away from the granite at over 80°. In places along the eastern contact, the granite is somewhat porphyritic and satellitic bodies of granite and porphyritic microgranite intrude the country rocks to the east, north and northwest of the main pluton ; these bodies are too small to be shown on Fig. 1, having outcrop areas of only a few thousand square metres.

Chemical data for the Gocup Granite are presented in Table 1 ; radiometric ages for four samples have been determined by Dr. J. R. Richards (Research School of Earth Sciences, Australian National University). K–Ar data on biotites and muscovites yield a mean age of 410$\pm$4 m.y. and a Rb–Sr age of 408 m.y. has also been determined. The significance of these data will be discussed later.

Minjary Volcanics

A succession of porphyritic and banded rhyolites unconformably overlies both the Silurian country rocks and the northwestern margin of the Gocup Granite, in the vicinity of Minjary Mountain. The name Minjary Volcanics is proposed for this sequence which has a maximum thickness in excess of 350 m, and may be broadly divided into two units :

(1) a lower series of massive, porphyritic lava flows and ignimbrites ;
(2) an upper unit of fine-grained, banded rhyolite.

The porphyritic rocks of the lower part of the Minjary Volcanics are rhyolitic to rhyodacitic in composition, and purple to brown in colour. In some specimens the presence of fragmental and welded textures suggests an ignimbritic character. The rocks consist of phenocrysts of quartz, oligoclase and, to a lesser extent, sanidine, in a fine-grained groundmass, chiefly of quartz and alkali feldspar. Biotite, commonly replaced by chlorite, forms occasional glomeroporphyritic aggregates. Sphene, pyrite, zircon, apatite and monazite are present as accessories, while epidote, muscovite, calcite, zeolites and prehnite occur as secondary phases. Spherulitic and devitrified glassy textures are often present, but flow banding is rarely prominent.

Conglomeratic bands with a maximum individual thickness of about 5 m occur at various stratigraphic levels in a zone about 60 m thick near the top of the lower, porphyritic section of the Minjary Volcanics. The detritus in these poorly-sorted rocks consists of angular pebbles up to 8 cm in diameter of coarse-grained leucogranite and rounded to subangular fragments of quartz-rich rhyolite and, rarely, schist and phyllite. The matrix contains angular pink feldspar grains and quartz fragments in a purple silt that is similar in colour to much of the underlying porphyritic rhyolite. Broken tourmaline needles extracted from the matrix of this conglomerate possess optical properties identical with those of the deep indigo tourmaline of the Gocup Granite. Associated grits and arkoses contain angular to rounded grains of quartz and pink feldspar with lithic fragments, again set in a fine-grained, purple matrix. The lithology of these rocks suggests strongly that they were derived in part from the underlying Gocup Granite or a very similar body, and from the local volcanic rocks.

Southwest of Minjary Mountain, non-porphyritic, massive to banded rhyolite overlies the porphyritic volcanics and intercalated sediments. The banding, highly contorted in places, is textural rather than mineralogical and widths of individual bands range from less than 0·02 mm to more than 15 mm. Massive, non-banded rhyolites within this upper unit have a mineralogy similar to that of the banded rocks, being essentially composed of very fine-grained quartz and alkali feldspar. Much of this upper section of the Minjary Volcanics appears to represent fine ash-fall and flow material.

Palaeontology

Thinly-bedded, sparsely fossiliferous siltstones form discontinuous bands immediately above the base of the banded rhyolites, southwest of Minjary Mountain. Individual lenses have a maximum thickness of 1·5 m and are composed of fine lithic silt, quartz and broken shelly material. The presence of "Siluro-Devonian Brachiopoda . . . from the Minjary Ranges near Tumut" was first reported by Stephens (1882). Subsequently, fossils collected from the area by Mr. G. Hayes in 1900 were identified by Dun (1901) and again by Fletcher (1961). The locality was originally listed as "Portion 41, Parish Calafat, County Buccleugh" (Dun, 1901). Almost certainly, however, the true location was Portion 241, where the fossiliferous horizons of the Minjary Volcanics examined in this study are exposed. The fauna collected by the present author in 1971 is similar but more diverse than that listed by Dun or Fletcher, and comprises the following forms :

Brachiopoda : Articulata—
- *Howellella*? *jaqueti* (Dun)
- *Meristina* sp.
- *Molongia*? sp.
- *Strophonella manta* Talent
- *Strophodonta*? sp.
- *Nadiastrophia*? sp.
- *Hipparionyx*? sp.
- chonetid indet.
- *Isorthis alpha* (Gill)
- *Schizophoria convexa* Dun ?
- dalmanellid indet.

Coelenterata : Tabulata—
- cladoporid indet.

The tentative determinations are due to the fragmentary nature of the specimens and their generally poor state of preservation ; the silty matrix obscures much of the fine detail such as micro-ornament.

The assemblage has a definite Early Devonian aspect ; similar faunas characterised by *Howellella*? *jaqueti* have been recorded from several places in Cobar Basin and Parkes Platform deposits (cf. Packham, 1969, pp. 147–149 ; Strusz *et al.*, 1972, pp. 442–443 and chart). A lower to middle Siegenian age is consistent with all these occurrences ; the assemblage appears unlikely to be as old as Gedinnian or as young as Emsian. A mid-Early Devonian age is indicated for the Minjary Volcanics.

Regional Correlations

Pre-Devonian Strata

The belt of folded rocks of which the metasediments at Tumut are a part, extends north-northwest at least as far as Stockinbingal and Barmedman where it is overlain by extensive Quaternary deposits. South of Tumut, it narrows to less than 10 km in width, between the Bogong and Wondalga Granites.

Stratigraphic relations within the complex lower unit are unclear as only parts of it have been examined in detail. To the north, rocks similar to the Bullawyarra Schist have been named the Jindalee Beds by Basden (1974) who considers these units to represent strongly deformed oceanic crust. Tectonic syntheses by Scheibner (1973, 1974) propose that parts of these are as old as Cambrian and that the serpentinites associated with the Jindalee Beds, as well as the Coolac Serpentinite, represent the lower oceanic crust and upper mantle that formed the basement of the Cowra Trough. The age relationships on which this interpretation depends, however, must remain in doubt as the metasediments are all unfossiliferous. In this regard, the presence of conodont fragments in the marbles west of the Gocup Granite may be crucial, as these marbles are associated with serpentinites, quartz-magnetite rocks and basic schists similar to those of the Jindalee Beds, and the styles of deformation are comparable. Thus the inferred Silurian age for the metasediments northwest of Tumut could have important wider tectonic implications if regional correlations can be established.

Marble occurs elsewhere in the low-grade, foliated metasediments, at localities near Gilmore, west of Brungle, and east of Gilmore Creek some 20 km south of Tumut, where it is again associated with serpentinite and quartz-iron oxide rocks (Bradley, 1968). Near the Murrumbidgee River south of Nangus, Vallance (1953) has described serpentine rock, marble and jasper-iron oxide rocks that occur in close proximity within a zone of low-grade, folded metasediments.

Regional correlations with the Blowering Beds are less tenuous. The " Blowering Porphyry " was originally described from between Tumut and Talbingo (Hall and Relph, 1956 ; Adamson, 1960*a*) where it is intruded by the Bogong Granite. Ashley *et al.* (1971) and Basden (1974) have extended the mapped area of this unit north and northeast of Tumut to beyond Cootamundra. Sedimentary material associated with the dominantly rhyodacitic extrusive rocks and pyroclastics has varying prominence over the areas examined and includes volcanic and calcareous sandstones, siltstone, mudstone, chert and conglomerate. The only known fossils are those recorded by Ashley *et al.* (1971) which indicate a Middle to Late Silurian age.

Similar rhyolitic to dacitic volcanics, with associated sediments and more basic volcanics, are common in the southern part of the Cowra Trough where they occur over extensive areas around the Burrinjuck-Young Batholith. These units include the Goobarragandra Beds (Ashley *et al.*, 1971), Douro Volcanics (Brown, 1941) as now expanded, Canowindra Porphyry (Stevens, 1952 ; Ryall, 1965) and Frampton Volcanics (Basden, 1974), all of which have been assigned a Middle or Late Silurian age, and at least parts of the Illunie Rhyolite (Adamson, 1960*b*), Wyora Porphyry (Strusz, 1971) and Peppercorn Beds (Strusz, 1971). This last unit is in need of subdivision : it includes limestones that are as old as Llandoverian (Nicoll and Rexroad, 1974) as well as the rhyolites and dacites that are of interest here. It has been suggested (Ashley and Basden, 1973 ; Basden, 1974) that some of the volcanic units are closely related to the batholith they surround. Detailed chemical and mineralogical studies of these " porphyries " and the various rocks of the Burrinjuck-Young Batholith (Barkas, in prep.) point to a genetic association. It is proposed to refer to these related volcanic rocks that surround and are in part intruded by this batholith as the Wiradjuri Volcanics. This is a collective term and does not supersede the existing formation names of its constituent units. The name is taken from that of an Aboriginal tribe that inhabited a wide area centred around the Lachlan and Murrumbidgee Rivers (Tindale, 1940).

Early Devonian Correlations

Acid volcanism of Early Devonian age was not uncommon in the southern part of the Cowra Trough, where its products, like the Minjary Volcanics, rest unconformably on older strata. About 15 km northeast of the Gocup Granite, 100 m of rhyolitic ignimbrite (the Gatelee Ignimbrite) overlies the Blowering Beds and older rocks (Ashley *et al.*, 1971). Though banding is there more prominent, much of this unit exhibits a striking resemblance to the purple and brown rhyolites of the Minjary Volcanics.

Forty kilometres south-southeast of Tumut, the rhyolitic Buddong Volcanics, the lowest unit of the Lower to ?Middle Devonian Boraig Group, lies unconformably above the Silurian Ravine Beds (Moye *et al.*, 1969). The Buddong Volcanics are themselves overlain east of Ravine by beds of the Byron Range Group, the middle part of which (the Lick Hole Limestone) contains a fauna similar to that of part of the Murrumbidgee Group in the Taemas-Cavan area (Moye *et al.*, 1969, p. 145). As this fauna is now considered to be Emsian in age (Chatterton, 1973) a close time-correlation must exist between the Minjary and

Buddong Volcanics. Well-exposed sections of this latter unit in the east of the Boraig Basin and near Lobs Hole reveal a sequence strikingly analogous to the Minjary Volcanics: about 100 m of massive and banded, purple, porphyritic ignimbrites are overlain by conglomerates and grits, followed by more rhyolite. The sediments contain fragments of leucogranite, rhyolite and chert. It is envisaged that the lower part of the Minjary Volcanics, the Gatelee Ignimbrite and at least part of the Buddong Volcanics are stratigraphically as well as lithologically similar, and form an Early Devonian " rhyolite association " whose significance will be discussed later.

A similar analogy is apparent to the north. Basden (1974) notes that " rhyolitic lavas with an interbedded conglomeratic member occur to the west of Cootamundra, unconformably overlying the Frampton Volcanics ". She refers to this unit as the Cootamundra Volcanics and includes shale which conformably overlies the rhyolite and contains the *Howellella? jaqueti* fossil assemblage (Sherwin, unpubl., quoted by Basden, 1974) in her definition of this unit.

East of the Indi River near the Victorian border, 175 km south of Tumut, strongly folded, low-grade metasediments and acid to intermediate volcanics of the late Middle to early Upper Silurian Cowombat Group are overlain by rhyolites and rhyodacites of the Snowy River Volcanics with a marked angular unconformity (Moye *et al.*, 1969). The presence in Victoria of Emsian strata overlying the Snowy River Volcanics restricts the age of this unit to Early Devonian, while the similarity with the Tumut region is further enhanced by the observation of Talent (1965) that granitic rocks intrude the Cowombat Group in Victoria, but are overlain by the Snowy River Volcanics.

In the southeastern part of the Cowra Trough, near Bowning and at Cooleman Plains, the rhyolitic Mountain Creek Volcanics, of Early Devonian age, again appear to occupy a similar stratigraphic and structural position to the volcanic formations described above.

Leucogranites of the Tumut District

Evidence suggesting the stratigraphic equivalence of the rhyolitic rocks of the Minjary Volcanics, Gatelee Ignimbrite and Buddong Volcanics has been reviewed. Examination of the leucogranitic intrusions spatially related to these volcanics reveals a similar close association.

The *Bogong Granite* (Hall and Relph, 1956) is by far the largest of these; it outcrops over an area exceeding 320 km^2 (see Fig. 1) and has been described in part by Ashley *et al.* (1971). A composite mass, it intrudes units of the Wiradjuri Volcanics as well as the non-volcanic Silurian sequence in the south (Ravine Beds and Cave Creek Limestone). The K–Ar age of 385 m.y. reported by Ashley *et al.* has been revised (J. R. Richards, pers. comm.) to 410 m.y. to take account of revised decay constant determinations. A deuterically altered specimen of the Bogong Granite analysed at the same time yields a revised age of 390 m.y. which can be confidently considered to be younger than the age of intrusion. These radiometric data indicate that the Bogong and Gocup Granites are of the same age.

The *Killimicat Adamellite* (Ashley *et al.*, 1971) intrudes Silurian rocks to the north of the Bogong Granite. Chemically, petrographically and in hand specimen it is almost identical to large parts of the latter, and Ashley *et al.* have suggested that it represents a " cupola-like extension " of the Bogong Granite.

The *Lobs Hole Adamellite* (Adamson, 1957) is a small granitic body with an outcrop area of less than 3 km^2 at the south western margin of the Boraig Basin, near the now-submerged locality of Lobs Hole, on the Tumut River. This rock is characterised by phenocrysts of alkali feldspar and oligoclase up to 15 mm long that comprise from 50 to 85% of the mode, with interstitial micrographic quartz-feldspar intergrowths making up the bulk of the remainder. Most of the phenocrysts are clouded with alteration products ; the margins of many have been resorbed, while others have albitic or micrographic overgrowths. Quartz forms occasional clear, irregular phenocrysts ; biotite and subordinate hornblende jointly account for less than about 5% of the mode and are usually interstitial, but sometimes partly replace or mantle the phenocrysts.

This unusual rock appears to be genetically related to the rhyolites of the Buddong Volcanics within which it is situated. The porphyritic nature of the volcanics shows that the lavas and ash flows that formed them contained suspended phenocrysts at the time of extrusion. The textures of the Lobs Hole Adamellite suggest that it formed in a sub-volcanic chamber from a crystal-rich magmatic residue with interstitial rhyolitic liquid, that was not erupted : a multi-stage cooling history is apparent. Variations within the body appear gradational and are due to differing proportions of phenocrysts and interstitial material : some specimens (e.g. no. 9, Table 1) represent little more than a welded mass of phenocryst fragments.

Contact metamorphism around the Bogong Granite and Killimicat Adamellite is more marked in places than that adjacent to the Gocup Granite. It is common in the Lachlan Fold Belt for the degree of thermal metamorphism by the Murrumbidgee-type granites of Vallance (1969) and their associated leucogranites to be dependent on the nature of the country rocks as well as on the temperature difference across the contact. The Bogong Granite intrudes a variety of lithologies and illustrates this proposition : in psammopelitic rocks of the Bumbolee Creek and Ravine Beds, for example, contact effects are generally very slight ; similarly the rhyodacites of the Wiradjuri Volcanics exhibit recrystallisation and growth of secondary biotite clusters visible in hand specimen only within a few tens of metres of the contact. Elsewhere, however, the Bogong Granite intrudes the Coolac Serpentinite and associated basic rocks, and extensive high-grade hornfelses are developed (Ashley *et al.*, 1971), while to the south, massive andradite-hedenbergite and andradite-magnetite skarns are present in the belt of undifferentiated Silurian rocks shown on Fig. 1. At Black Perry Mountain (8 km west of Talbingo) and elsewhere, these skarns occur up to 3 km from the exposed margin of the granite.

Basic and silicified hornfelses make up the Wermatong Amphibolite of Adamson (1960*a*) which appears to correspond on the western margin of the Bogong Granite to some of the metamorphosed basic rocks recorded by Ashley *et al.* (1971) on the eastern side. The Wermatong Amphibolite and the basic rocks within the Goobarragandra Beds are taken to be part of the newly-defined Wiradjuri Volcanics.

Blacks Flat Diorite

To the north of the main outcrop area of the Gatelee Ignimbrite, a diorite stock intrudes both the Bullawyarra Schist and Blowering Beds. This body was mapped in detail by Thrum (1972) who named it the Blacks Flat Diorite. It has an outcrop area of about 4 km^2 that is irregular in shape, but elongated north-south.

Much of the body is composed of a medium-grained diorite whose two main mineral constituents are sodic oligoclase and hornblende, the former nearly always dominant ; the content of potassium feldspar is variable, ranging up to about 20% of the mode. Quartz, sphene, apatite, magnetite, allanite and zircon are almost constant accessories, while small amounts of chloritised biotite, calcite and epidote are often present as secondary phases. The hornblende is hastingsitic with $2V_\alpha \simeq 55°$, $Z \wedge c \simeq 29°$ and marked pleochroism (X = very pale yellow-green, Y = yellow-green, Z = deep green). Its composition, determined by microprobe analysis, is

$$K_{0\cdot26}Na_{0\cdot58}Ca_{1\cdot85}Fe_{2\cdot56}Mn_{0\cdot07}Mg_{2\cdot06}Ti_{0\cdot15}Al_{0\cdot37}\ (Si_{6\cdot4}Al_{1\cdot6}O_{22})\ (OH,F)_2.$$

Most of this hornblende is present as subhedral, elongate grains that are sometimes clustered ; intergrowths with potassium feldspar and inclusions of sphene and apatite are common. Much of the feldspar is pink in hand specimen ; microscopic examination shows this to be due to a very fine clouding of most grains with alteration products. By contrast the hornblende is generally free from any signs of alteration.

Contact effects of the Blacks Flat Diorite appear limited to a partial recrystallisation and hardening of the country rocks within a zone never more than about 10 m wide. Xenoliths of partly-recrystallised country rock are common throughout the intrusion and apparent roof pendants up to 600 m across have been mapped by Thrum (1972). The mass is noticeably finer-grained and somewhat porphyritic near its southern end and, to the north and south, several satellitic and dyke-like bodies of similar dioritic rocks intrude the surrounding Bullawyarra Schist. All these features suggest that, like the Gocup Granite, this body is exposed at a level not far below its original roof.

As Thrum (1972) pointed out, the Blacks Flat Diorite intrudes part of the Blowering Beds and is thus no older than Late Silurian. On the available chemical and petrographic evidence, however, it is not genetically related to the Early Devonian intrusive rocks described elsewhere in this paper, although it does appear to occupy a somewhat analogous crustal position.

Chemical Data

Seventeen bulk-rock analyses of relevance to the discussion in this paper are listed in Table 1. No previous chemical data have been published on the Gocup Granite, Minjary Volcanics, Lobs Hole Adamellite or Boraig Group, but the analyses of the Bogong Granite, Killimicat Adamellite and Gatelee Ignimbrite presented here should be considered in association with those of these units tabulated by Ashley *et al.* (1971) and Ashley and Basden (1973). When this is done, a clear chemical coherence is apparent among the members of the two igneous associations (leucogranites and rhyolites) described in this paper, as is the similarity between these two groups. A detailed study of a much larger number of analyses will form the subject of a subsequent paper.

Of the Bogong Granite analyses, numbers 4 and 5 in Table 1 represent biotite leucogranites typical of the pluton as a whole, while 6 and 7 are of variants of very limited areal extent. The atypical (e.g. high TiO_2, Sr, Zr ; low SiO_2, Rb) and variable composition of the Lobs Hole Adamellite (nos 8, 9, 10) reflect its unusual, partly cumulus origin. These analyses, however, show interesting similarities to that of a rhyodacite unusually rich in feldspar phenocrysts from the Gatelee Ignimbrite (no. 11).

The Middle Devonian Cumberland Rhyolite lies at the top of the volcanic succession in the Boraig Basin and so is appreciably younger than, but conformable with, the rhyolites of the Buddong Volcanics. Its analysis (no. 15), however, stands clearly apart from those of the rhyolites considered here to be co-genetic. Similarly, the Blacks Flat Diorite may be distinguished from the other granitic analyses on many counts, perhaps the most striking of which is its SrO content of 0·29 weight per cent.

Stratigraphic Synthesis

A stratigraphic scheme consistent with the radiometric, palaeontological and structural data discussed in this paper is shown in Fig. 2. The Gocup Granite, Killimicat Adamellite and Lobs Hole Adamellite all have petrographic and chemical analogues in the composite Bogong Granite and in the light of the coherent radiometric and structural data, these plutons are considered to comprise a post-tectonic sub-volcanic leucogranite association of Early (or Earliest) Devonian age.

TABLE 1

Chemical data for some igneous rocks of the Tumut district

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SiO_2 ..	74·01	74·81	75·68	76·16	74·11	75·85	72·15	71·14	60·89	64·84	66·01	73·78	74·42	72·34	75·72	53·79	54·94
Al_2O_3 ..	12·74	13·63	12·71	12·50	13·70	13·31	13·91	14·22	14·98	14·26	16·23	13·20	12·18	14·30	12·22	15·79	17·20
Fe_2O_3 ..	0·56	0·58	0·39	0·26	0·82	0·44	0·65	1·67	2·90	1·98	1·91	1·23	0·47	0·33	0·86	2·51	2·71
FeO ..	1·77	0·46	0·84	0·64	1·32	0·50	1·81	1·98	3·49	3·69	1·27	0·64	1·58	0·63	0·95	6·14	4·54
MnO ..	0·03	0·02	0·02	0·03	0·04	0·05	0·02	0·05	0·13	0·09	0·08	0·03	0·05	0·01	0·04	0·19	0·19
MgO ..	0·50	0·15	0·31	0·12	0·51	0·20	0·60	0·42	1·02	0·81	0·81	0·52	0·62	0·45	0·23	4·02	3·26
CaO ..	0·34	0·39	0·98	0·98	1·37	0·82	2·19	0·36	4·20	2·59	2·98	0·90	0·61	0·44	0·12	9·21	5·53
Na_2O ..	2·52	3·83	3·62	3·54	3·37	3·41	3·97	4·40	6·75	5·57	4·25	3·71	3·10	3·99	3·17	2·93	4·99
K_2O ..	5·46	4·59	4·59	4·97	4·39	4·31	3·73	3·41	0·57	2·34	3·94	4·79	5·49	5·49	5·53	1·24	3·22
H_2O^+ ..	1·13	0·90	0·35	0·35	0·36	0·30	0·40	1·25	1·87	1·78	1·10	0·61	0·76	1·55	0·62	1·53	1·51
H_2O^- ..	0·15	0·17	0·14	0·15	0·07	0·12	0·09	0·31	0·20	0·24	0·30	0·16	0·18	0·15	0·19	0·16	0·09
TiO_2 ..	0·22	0·07	0·19	0·18	0·28	0·11	0·35	0·42	1·05	0·68	0·46	0·30	0·32	0·36	0·14	1·76	0·72
P_2O_5 ..	0·20	0·29	0·04	0·02	0·05	0·02	0·05	0·12	0·40	0·23	0·12	0·04	0·06	0·05	0·02	0·37	0·48
CO_2 ..	0·08							0·08	1·02	0·49	0·24						
Total ..	99·71	99·89	99·86	99·90	100·39	99·44	99·92	99·83	99·47	99·59	99·70	99·91	99·84	100·09	99·81	99·64	99·38
Trace elements in p.p.m.																	
Y ..	45	35	58	49	44	28	45	66	67	70	47	41	32	56	350		33
Sr ..	71	75	89	56	86	109	172	167	346	283	300	200	170	230	32		2430
Zr ..	194	120	186	183	168	120	245	450	400	530	245	215	155	275	213		203
Rb ..	317	200	205	185	225	260	157	120	25	65	130	200	217	164	240		70

Five-figure specimen numbers (in brackets) refer to the catalogue and collections of the Department of Geology and Geophysics, University of Sydney. Grid references are quoted from the Wagga Wagga geological sheet, scale 1 : 250,000 (Adamson and Loudon, 1966). Analyses by X-ray fluorescence spectrometry, except for Na_2O (atomic absorption), FeO (titrimetry), H_2O (gravimetry), CO_2 (combustion).

Key :
1. Biotite leucogranite (48245). Gocup Granite. 5 km E. of Tumut, G.R. 614640.
2. Biotite leucogranite (48247). Gocup Granite. 8·8 km NE. of Tumut. G.R. 612643.
3. Biotite leucogranite (48254). Killimicat Adamellite. 12 km N. of Tumut. G.R. 625651.
4. Biotite leucogranite (48242). Bogong Granite. 22 km SSE. of Tumut. G.R. 629618.
5. Biotite leucogranite (48289). Bogong Granite. 14 km SE. of Tumut. G.R. 634633.
6. Fine-grained biotite leucogranite (48240) Bogong Granite. Marginal phase, 13 km E. of Tumut. G.R. 634636.
7. Hornblende biotite granite (48287). Bogong Granite. 16·5 km SE. of Tumut. G.R. 635627.
8. Porphyritic, granophyric leucogranite (48259). Lobs Hole Adamellite. G.R. 632583.
9. Porphyritic, granophyric leucogranite (48260). Lobs Hole Adamellite. G.R. 633584.
10. Porphyritic, granophyric leucogranite (48261). Lobs Hole Adamellite. G.R. 632584.
11. Rhyodacite, unusually rich in feldspar phenocrysts (48257). Gatelee Ignimbrite. 15 km N. of Tumut. G.R. 622662.
12. Banded rhyolite (48258). Gatelee Ignimbrite. 15 km N. of Tumut. G.R. 620661.
13. Porphyritic rhyolite (48262). Minjary Volcanics. 600 m S. of Minjary Mountain. G.R. 612648.
14. Ignimbritic rhyolite (48280). Buddong Volcanics. 3 km ENE. of Talbingo. G.R. 631606.
15. Rhyolite (48284). Cumberland Rhyolite. 11 km SSE. of Talbingo. G.R. 636595.
16. Andesitic basalt (porphyritic, partially degraded) (48283). Talbingo Basalt. 7·5 km SSE. of Talbingo. G.R. 632598.
17. Diorite (48461). Blacks Flat Diorite. 25 km N. of Tumut. G.R. 623666.

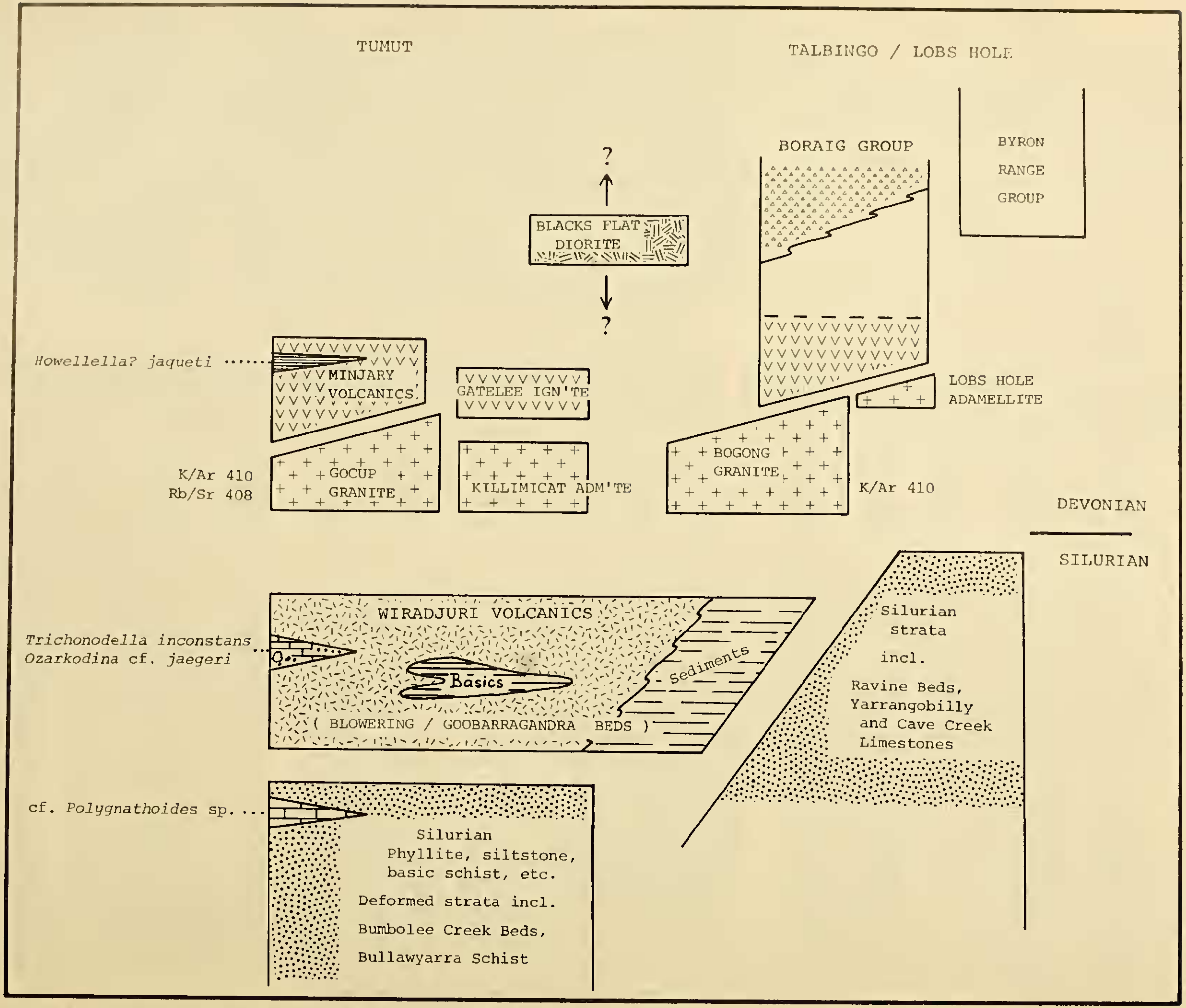

Fig. 2. Sketch of Siluro-Devonian stratigraphic relations in the Tumut region, N.S.W. (not to scale). See also Fig. 1.

The absolute age of the Silurian-Devonian boundary is as equivocal as its lithostratigraphic position (Philip, 1974). Brooks and Leggo (1972) quote 413 and 430 m.y. as possible limiting values, but the latter estimate, although based on " local " data from the Canberra area (Bofinger *et al.*, 1970) may well be subject to stratigraphic imprecision (Talent *et al.*, 1975, p. 27). An age for the boundary of between 410 and 415 m.y. would appear acceptable in the light of the data summarised by Lambert (1971), and indeed such an age is suggested by this study.

In any case, a close temporal relationship exists between the leucogranite and rhyolite associations and, as the volcanism partly overlaps in age and partly postdates the granite emplacement, it may represent the culmination of an Early Devonian episode of high-level acid magmatism. The older the absolute age of the Siluro-Devonian boundary, the more restricted must have been the duration of this magmatic episode. By Middle Devonian time, volcanic activity had resumed in the Boraig Basin with the eruption of the Talbingo Basalt and Cumberland Rhyolite after a break represented stratigraphically by the sediments of the Saddle Tuff and Landers Creek Formation, described by Moye *et al.* (1969).

Thus it may be postulated that the Buddong Volcanics, Gatelee Ignimbrite and Minjary Volcanics represent the extrusive equivalents of the Bogong Granite, Lobs Hole Adamellite, Killimicat Adamellite and Gocup Granite. In this regard, the Minjary Volcanics and the outcrop areas of the Gatelee Ignimbrite show a sub-radial distribution around the two northernmost plutons that may well be genetically significant.

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